

## CHAPTER 26 (Odd)

1.  $Z_i = \frac{E_i}{I_i}; I_i = \frac{V_R}{R} = \frac{1.05 \text{ V} - 1.00 \text{ V}}{47 \Omega} = \frac{50 \text{ mV}}{47 \Omega} = 1.064 \text{ mA}$   
 $Z_i = \frac{E_i}{I_i} = \frac{1.05 \text{ V}}{1.064 \text{ mA}} = 986.84 \Omega$
  
3. a.  $I_{i_1} = \frac{E_{i_1}}{Z_{i_1}} = \frac{20 \text{ mV}}{2 \text{ k}\Omega} = 10 \mu\text{A}$   
 b.  $Z_{i_2} = \frac{E_{i_2}}{I_{i_2}} = \frac{1.8 \text{ V}}{0.4 \text{ mA}} = 4.5 \text{ k}\Omega$   
 c.  $E_{i_3} = I_{i_3} Z_{i_3} = (1.5 \text{ mA})(4.6 \text{ k}\Omega) = 6.9 \text{ V}$
  
5.  $E_{o_{\text{peak}}} = E_{g_{\text{peak}}} - V_{R_{\text{peak}}} = 2 \text{ V } \angle 0^\circ - 40 \times 10^{-3} \text{ V } \angle 0^\circ = 1.96 \text{ V } \angle 0^\circ$   
 $I_{\text{peak}} = \frac{V_{R_{\text{peak}}}}{R_s} = \frac{40 \text{ mV}}{0.91 \text{ k}\Omega} = 43.96 \mu\text{A}$   
 $Z_o = \frac{E_o}{I_R} = \frac{1.96 \text{ V } \angle 0^\circ}{43.96 \mu\text{A}} = 44.59 \text{ k}\Omega$
  
7.  $Z_o = \frac{E_{o_{p-p}}}{I_{o_{p-p}}} = \frac{E_{g_{p-p}} - V_{R_{p-p}}}{I_{o_{p-p}}} = \frac{0.8 \text{ V} - 0.4 \text{ V}}{40 \mu\text{A}} = 10 \text{ k}\Omega$   
 $V_{R_{p-p}} = 2 \text{ div}[0.2 \text{ V/div.}] = 0.4 \text{ V}$   
 $E_{g_{p-p}} = 4 \text{ div}[0.2 \text{ V/div.}] = 0.8 \text{ V}$   
 $I_{o_{p-p}} = \frac{V_{R_{p-p}}}{10 \text{ k}\Omega} = \frac{0.4 \text{ V}}{10 \text{ k}\Omega} = 40 \mu\text{A}$
  
9. a.  $A_v = \frac{E_o}{E_i} = A_{v_{NL}} \frac{R_L}{R_L + R_o} = (-3200) \frac{(5.6 \text{ k}\Omega)}{5.6 \text{ k}\Omega + 40 \text{ k}\Omega} = -392.98$   
 b.  $A_{v_T} = \frac{E_o}{E_g} = \frac{E_o}{E_i} \cdot \frac{E_i}{E_g}$   
 with  $E_i = \frac{Z_i E_g}{Z_i + R_g}$  and  $\frac{E_i}{E_g} = \frac{Z_i}{Z_i + R_g}$   
 $A_{v_T} = \frac{E_o}{E_i} \cdot \frac{Z_i}{Z_i + R_g} = (-392.98) \frac{(2.2 \text{ k}\Omega)}{2.2 \text{ k}\Omega + 0.5 \text{ k}\Omega} = -320.21$

$$\begin{aligned}
 11. \quad a. \quad A_v &= \frac{E_o}{E_i} = A_{vNL} \frac{R_L}{R_L + R_o} \\
 -160 &= A_{vNL} \frac{2 \text{ k}\Omega}{2 \text{ k}\Omega + 28 \text{ k}\Omega} = A_{vNL}(0.0667) \\
 A_{vNL} &= -2398.8
 \end{aligned}$$

$$\begin{aligned}
 b. \quad E_o &= -I_o R_L = -(4 \text{ mA})(2 \text{ k}\Omega) = -8 \text{ V} \\
 A_v &= \frac{E_o}{E_i} = -160 \\
 E_i &= \frac{E_o}{-160} = \frac{-8 \text{ V}}{-160 \text{ V}} = 50 \text{ mV}
 \end{aligned}$$

$$\begin{aligned}
 c. \quad I_i &= \frac{E_g - E_i}{R_g} = \frac{70 \text{ mV} - 50 \text{ mV}}{0.4 \text{ k}\Omega} = 50 \text{ }\mu\text{A} \\
 Z_i &= \frac{E_i}{I_i} = \frac{50 \text{ mV}}{50 \text{ }\mu\text{A}} = 1 \text{ k}\Omega
 \end{aligned}$$

$$\begin{aligned}
 13. \quad a. \quad A_G &= A_v^2 \frac{R_i}{R_L} \\
 &= (-392.98)^2 \frac{2.2 \text{ k}\Omega}{5.6 \text{ k}\Omega} \\
 &= 6.067 \times 10^4
 \end{aligned}$$

$$\begin{aligned}
 A_v &= A_{vNL} \frac{R_L}{R_L + R_o} \\
 &= (-3200) \left[ \frac{5.6 \text{ k}\Omega}{5.6 \text{ k}\Omega + 40 \text{ k}\Omega} \right] \\
 &= -392.98
 \end{aligned}$$

$$\begin{aligned}
 A_G &= -A_v A_i \\
 &= -(-392.98)(154.39) \\
 &= 6.067 \times 10^4
 \end{aligned}$$

$$\begin{aligned}
 A_i &= -A_{vNL} \frac{R_i}{R_L + R_o} \\
 &= -(-3200) \left[ \frac{2.2 \text{ k}\Omega}{5.6 \text{ k}\Omega + 40 \text{ k}\Omega} \right] \\
 &= 154.39
 \end{aligned}$$

$$\begin{aligned}
 b. \quad A_{v_T} &= A_v \frac{Z_i}{Z_i + R_g} = (-392.98) \left[ \frac{2.2 \text{ k}\Omega}{2.2 \text{ k}\Omega + 0.5 \text{ k}\Omega} \right] = -320.21 \\
 A_{i_T} &= -A_{v_T} \frac{R_g + Z_i}{R_L} = -(-320.21) \left[ \frac{0.5 \text{ k}\Omega + 2.2 \text{ k}\Omega}{5.6 \text{ k}\Omega} \right] = 154.39 \\
 A_{G_T} &= A_{v_T}^2 \left[ \frac{R_g + R_i}{R_L} \right] = (-320.21)^2 \left[ \frac{0.5 \text{ k}\Omega + 2.2 \text{ k}\Omega}{5.6 \text{ k}\Omega} \right] = 4.94 \times 10^4 \\
 A_{G_T} &= -A_{v_T} A_{i_T} = -(-320.21)(154.39) = 4.94 \times 10^4
 \end{aligned}$$

$$15. \quad a. \quad A_{v_T} = A_{v_1} \cdot A_{v_2} = (-30)(-50) = 1500$$

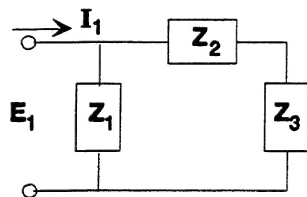
$$b. \quad A_{i_T} = A_{v_T} \frac{Z_{i_1}}{R_L} = (1500) \left[ \frac{1 \text{ k}\Omega}{8 \text{ k}\Omega} \right] = 187.5$$

$$c. \quad A_{i_1} = -A_{v_1} \frac{Z_{i_1}}{R_{L_1}} = -(-30) \left[ \frac{1 \text{ k}\Omega}{2 \text{ k}\Omega} \right] = 15$$

$$A_{i_2} = -A_{v_2} \frac{Z_{i_2}}{R_{L_2}} = -(-50) \left( \frac{2 \text{ k}\Omega}{8 \text{ k}\Omega} \right) = 12.5$$

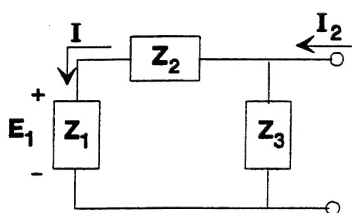
d.  $A_{i_T} = A_{i_1} \cdot A_{i_2} = (15)(12.5) = 187.5$  as above

17. a.



$$z_{11} = \frac{E_1}{I_1} \Big|_{I_2=0} = Z_1 \parallel (Z_2 + Z_3)$$

$$z_{11} = \frac{Z_1 Z_2 + Z_1 Z_3}{Z_1 + Z_2 + Z_3}$$



$$I = \frac{Z_3 I_2}{Z_1 + Z_2 + Z_3}$$

$$E_1 = I_1 Z_1 = \frac{(Z_3 I_2)(Z_1)}{Z_1 + Z_2 + Z_3}$$

$$z_{12} = \frac{E_1}{I_2} \Big|_{I_1=0} = \frac{Z_1 Z_3}{Z_1 + Z_2 + Z_3}$$

$$z_{21} = \frac{E_2}{I_1} \Big|_{I_2=0} \quad \text{Mirror image of } z_{12}$$

$$\therefore z_{21} = \frac{Z_1 Z_3}{Z_1 + Z_2 + Z_3}$$

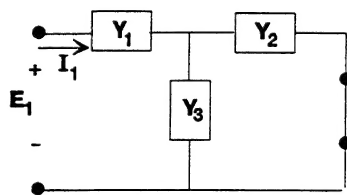
$$z_{22} = \frac{E_2}{I_2} \Big|_{I_1=0} \quad \text{Mirror image of } z_{11}$$

$$\therefore z_{22} = Z_3 \parallel (Z_1 + Z_2)$$

$$= \frac{Z_1 Z_3 + Z_2 Z_3}{Z_1 + Z_2 + Z_3}$$

b. —

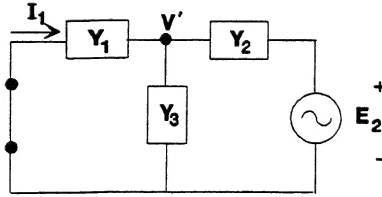
19. a.



$$y_{11} = \frac{I_1}{E_1} \Big|_{E_2=0} \quad Y_T = Y_1 \parallel (Y_2 + Y_3)$$

$$= \frac{Y_1(Y_2 + Y_3)}{Y_1 + Y_2 + Y_3}$$

$$= \frac{Y_1 Y_2 + Y_1 Y_3}{Y_1 + Y_2 + Y_3}$$



Nodal analysis:

$$V'[Y_1 + Y_2 + Y_3] = E_2 Y_2$$

$$V' = I_1 / Y_1$$

and

$$\frac{-I_1}{Y_1} [Y_1 + Y_2 + Y_3] = E_2 Y_2$$

$$y_{12} = \left. \frac{I_1}{E_2} \right|_{E_1=0} = \frac{-Y_1 Y_2}{Y_1 + Y_2 + Y_3}$$

$$y_{21} = \left. \frac{I_2}{E_1} \right|_{E_2=0} \quad \text{Mirror image of } y_{12}$$

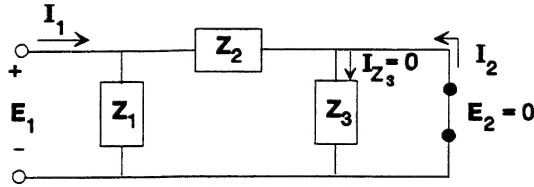
$$\therefore y_{21} = \frac{-Y_1 Y_2}{Y_1 + Y_2 + Y_3}$$

$$y_{22} = \left. \frac{I_2}{E_2} \right|_{E_1=0} \quad \text{Mirror image of } y_{11}$$

$$y_{22} = Y_T = Y_2 \parallel (Y_1 + Y_3)$$

$$= \frac{Y_1 Y_2 + Y_2 Y_3}{Y_1 + Y_2 + Y_3}$$

21.

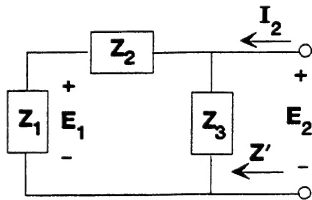


$$h_{11} = \left. \frac{E_1}{I_1} \right|_{E_2=0} = Z_T = Z_1 \parallel Z_2 = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Using the above figure:

$$\text{CDR: } I_2 = \frac{-Z_1(I_1)}{Z_1 + Z_2}$$

$$h_{21} = \left. \frac{I_2}{I_1} \right|_{E_2=0} = \frac{-Z_1}{Z_1 + Z_2}$$



$$h_{12} = \left. \frac{E_1}{E_2} \right|_{I_1=0}$$

$$\text{VDR: } E_1 = \frac{Z_1 E_2}{Z_1 + Z_2}$$

$$h_{12} = \left. \frac{E_1}{E_2} \right|_{I_1=0} = \frac{Z_1}{Z_1 + Z_2}$$

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Using above figure:

$$h_{22} = \left. \frac{I_2}{E_2} \right|_{I_1=0} : Z' = Z_3 \parallel (Z_1 + Z_2) = \frac{Z_1 Z_3 + Z_2 Z_3}{Z_1 + Z_2 + Z_3}$$

$$h_{22} = \frac{1}{Z'} = \frac{Z_1 + Z_2 + Z_3}{Z_1 Z_3 + Z_2 Z_3}$$

23.  $h_{11} = \left. \frac{E_1}{I_1} \right|_{E_2=0}$

$$Y' = Y_1 \parallel (Y_2 + Y_3)$$

$$Y' = \frac{Y_1 Y_2 + Y_1 Y_3}{Y_1 + Y_2 + Y_3}$$

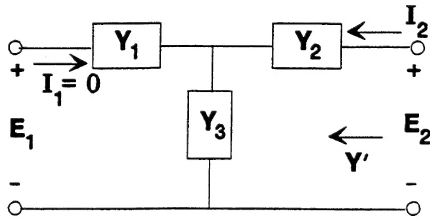
$$h_{11} = \frac{1}{Y'} = \frac{Y_1 + Y_2 + Y_3}{Y_1 Y_2 + Y_1 Y_3}$$

$$h_{21} = \left. \frac{I_2}{I_1} \right|_{E_2=0}$$

From above figure:

$$\text{CDR: } I_2 = \frac{-Z_3 I_1}{Z_3 + Z_2} = \frac{-I_1 / Y_3}{1/Y_3 + 1/Y_2}$$

$$\text{and } h_{21} = \left. \frac{I_2}{I_1} \right|_{E_2=0} = \frac{-1/Y_3}{1/Y_3 + 1/Y_2} = \frac{-Y_2}{Y_2 + Y_3}$$



$$h_{12} = \left. \frac{E_1}{E_2} \right|_{I_1=0}$$

$$\text{VDR: } E_1 = \frac{Z_3 E_2}{Z_3 + Z_2} = \frac{-1/Y_3 E_2}{1/Y_3 + 1/Y_2}$$

$$\text{and } E_1 = \frac{Y_2 E_2}{Y_2 + Y_3}$$

$$\text{with } h_{12} = \left. \frac{E_1}{E_2} \right|_{I_1=0} = \frac{Y_2}{Y_2 + Y_3}$$

$$h_{22} = \left. \frac{I_2}{E_2} \right|_{I_1=0} \quad Y' = \frac{Y_2 \cdot Y_3}{Y_2 + Y_3} \quad (\text{from above figure})$$

$$h_{22} = \left. \frac{I_2}{E_2} \right|_{I_1=0} = Y' = \frac{Y_2 Y_3}{Y_2 + Y_3}$$

25. a. Eq. 26.45:

$$A_i = \frac{h_f}{1 + h_o Z_L} = \frac{50}{1 + \left[ \frac{1}{40 \text{ k}\Omega} \right] (2 \text{ k}\Omega)} = 47.62$$

- b. Eq. 26.46:

$$A_v = \frac{-h_f Z_L}{h_i(1 + h_o Z_L) - h_r h_f Z_L} = \frac{-50(2 \text{ k}\Omega)}{1 \text{ k}\Omega(1 + 0.05) - (4 \times 10^{-4})(50)(2 \text{ k}\Omega)} = -99$$

27.  $z_{11} = 1 \text{ k}\Omega \angle 0^\circ$ ,  $z_{12} = 5 \text{ k}\Omega \angle 90^\circ$ ,  $z_{21} = 10 \text{ k}\Omega \angle 0^\circ$ ,  $z_{22} = 2 \text{ k}\Omega - j4 \text{ k}\Omega$ ,  
 $Z_L = 1 \text{ k}\Omega \angle 0^\circ$

$$Z_i = \frac{E}{I} = z_{11} - \frac{z_{12}z_{21}}{z_{22} + Z_L} = 1 \text{ k}\Omega - \frac{(5 \text{ k}\Omega \angle 90^\circ)(10 \text{ k}\Omega)}{2 \text{ k}\Omega - j4 \text{ k}\Omega + 1 \text{ k}\Omega} = 9,219.5 \Omega \angle -139.40^\circ$$

$$Z_o = \frac{E_2}{I_2} = z_{22} - \frac{z_{12}z_{21}}{R_s + z_{11}} = 2 \text{ k}\Omega - j4 \text{ k}\Omega - \frac{(5 \text{ k}\Omega \angle 90^\circ)(10 \text{ k}\Omega)}{1 \text{ k}\Omega + 1 \text{ k}\Omega} = 29.07 \text{ k}\Omega \angle -86.05^\circ$$

29.  $h_{11} = \frac{z_{11}z_{22} - z_{12}z_{21}}{z_{22}} = \frac{(4 \text{ k}\Omega)(4 \text{ k}\Omega) - (2 \text{ k}\Omega)(3 \text{ k}\Omega)}{4 \text{ k}\Omega} = 2.5 \text{ k}\Omega$

$$h_{12} = \frac{z_{12}}{z_{22}} = \frac{2 \text{ k}\Omega}{4 \text{ k}\Omega} = 0.5$$

$$h_{21} = -\frac{z_{21}}{z_{22}} = -\frac{3 \text{ k}\Omega}{4 \text{ k}\Omega} = -0.75$$

$$h_{22} = \frac{1}{z_{22}} = \frac{1}{4 \text{ k}\Omega} = 0.25 \text{ mS}$$

## CHAPTER 26 (Even)

$$2. \quad Z_i = \frac{E_i}{I_i} = \frac{120 \text{ V} \angle 0^\circ}{6.2 \text{ A} \angle -10.8^\circ} = 19.35 \Omega \angle 10.8^\circ = 19 \Omega + j3.623 \Omega$$

$$f = 60 \text{ Hz: } R = 19 \Omega, L = \frac{X_L}{2\pi f} = \frac{3.623 \Omega}{2\pi(60 \text{ Hz})} = 9.61 \text{ mH}$$

$$4. \quad I_o = \frac{E_g - E_o}{R_s} = \frac{4 \text{ V} - 3.8 \text{ V}}{2 \text{ k}\Omega} = \frac{0.2 \text{ V}}{2 \text{ k}\Omega} = 0.1 \text{ mA}(p - p)$$

$$Z_o = \frac{E_o}{I_o} = \frac{3.8 \text{ V}(p - p)}{0.1 \text{ mA}(p - p)} = 38 \text{ k}\Omega$$

$$6. \quad E_{o(\text{peak})} = \sqrt{2} \cdot 0.6 \text{ V}_{(\text{rms})} = 0.849 \text{ V}$$

$$E_{o(p-p)} = 2(E_{o(\text{peak})}) = 2(0.849 \text{ V}) = 1.697 \text{ V}$$

$$I_o = \frac{E_g - E_o}{R_s} = \frac{1.8 \text{ V} - 1.697 \text{ V}}{2 \text{ k}\Omega} = 51.5 \mu\text{A}(p - p)$$

$$Z_o = \frac{E_o}{I_o} = \frac{1.697 \text{ V}(p - p)}{51.5 \mu\text{A}(p - p)} = 32.95 \text{ k}\Omega$$

$$8. \quad E_i = I_i Z_i = (10 \mu\text{A} \angle 0^\circ)(1.8 \text{ k}\Omega \angle 0^\circ) = 18 \text{ mV} \angle 0^\circ$$

$$E_{i(\text{peak})} = \sqrt{2} (18 \text{ mV}) = 25.46 \text{ mV}$$

$$E_{i(p-p)} = 2(25.46 \text{ mV}) = 50.92 \text{ mV}$$

$$A_{v_{NL}} = \frac{E_o}{E_i} = \frac{4.05 \text{ V} \angle 180^\circ}{50.92 \text{ mV} \angle 0^\circ} = 79.54 \angle 180^\circ = -79.54$$

$$10. \quad A_{v_{NL}} = \frac{-1400 \text{ mV}}{1.2 \text{ mV} \angle 0^\circ} = -1200$$

$$A_v = \frac{-192 \text{ mV}}{1.2 \text{ mV}} = -160$$

$$\begin{aligned} R_o &= R_L \left[ \frac{A_{v_{NL}}}{A_v} - 1 \right] \\ &= 4.7 \text{ k}\Omega \left[ \frac{-1200}{-160} - 1 \right] \\ &= 30.55 \text{ k}\Omega \end{aligned}$$

$$\begin{aligned} 12. \quad a. \quad A_i &= -A_{v_{NL}} \frac{R_i}{R_L + R_o} \\ &= \frac{-(-3200)(2.2 \text{ k}\Omega)}{5.6 \text{ k}\Omega + 40 \text{ k}\Omega} \\ &= 154.39 \end{aligned}$$

$$\begin{aligned}
\text{b. } A_{i_T} &= -A_{v_T} \left[ \frac{R_g + Z_i}{R_L} \right] \\
&= - \left[ \frac{A_v Z_i}{Z_i + R_g} \right] \left[ \frac{R_g + Z_i}{R_L} \right] \\
A_{i_T} &= -A_v \frac{Z_i}{R_L} = - \left[ A_{v_{NL}} \frac{R_L}{R_L + R_o} \right] \frac{Z_i}{R_L} \\
&= -A_{v_{NL}} \frac{Z_i}{R_L + R_o} \\
&= \frac{-(-3200)(2.2 \text{ k}\Omega)}{5.6 \text{ k}\Omega + 40 \text{ k}\Omega} \\
&= 154.39
\end{aligned}$$

$$\text{c. Same result since } I_i = I_g$$

$$\begin{aligned}
14. \text{ a. } A_i &= \frac{I_o}{I_i} = -A_v \frac{Z_i}{R_L} \\
&= \frac{-(-160)(0.75 \text{ k}\Omega)}{2 \text{ k}\Omega} \\
&= 60
\end{aligned}$$

$$\begin{aligned}
\text{b. } A_{G_T} &= \frac{P_L}{P_g} = A_{v_T}^2 \left[ \frac{R_g + R_i}{R_L} \right] \\
A_{v_T} &= A_v \frac{Z_i}{Z_i + R_g} \\
&= \frac{(-160)(0.75 \text{ k}\Omega)}{0.75 \text{ k}\Omega + 0.4 \text{ k}\Omega} = -104.35 \\
A_{G_T} &= (104.35)^2 \left[ \frac{0.4 \text{ k}\Omega + 0.75 \text{ k}\Omega}{2 \text{ k}\Omega} \right] \\
&= 6.261 \times 10^3
\end{aligned}$$

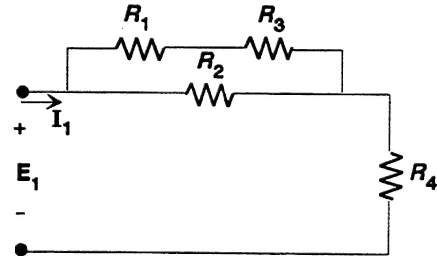
$$\begin{aligned}
16. \text{ a. } A_{v_T} &= A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \\
-6912 &= (-12)(A_{v_2})(-32) \\
A_{v_2} &= -18
\end{aligned}$$

$$\begin{aligned}
\text{b. } A_{i_1} &= \frac{-A_{v_1} Z_{i_1}}{R_{L_1}} = \frac{-A_{v_1} Z_{i_1}}{Z_{i_2}} \\
4 &= \frac{-(-12)(1 \text{ k}\Omega)}{Z_{i_2}} \\
Z_{i_2} &= 3 \text{ k}\Omega
\end{aligned}$$

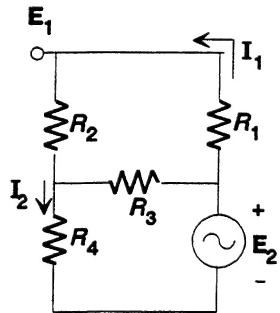


$$\begin{aligned}
 \text{c. } A_{i_3} &= \frac{-A_{v_3} Z_{i_3}}{R_{L_3}} = \frac{-(-32)(2 \text{ k}\Omega)}{2.2 \text{ k}\Omega} \\
 &= 29.09 \\
 A_{i_T} &= A_{i_1} \cdot A_{i_2} \cdot A_{i_3} \\
 &= (4)(26)(29.09) \\
 &= 3.025 \times 10^3
 \end{aligned}$$

$$\begin{aligned}
 18. \quad \text{a. } z_{11} &= \left. \frac{E_1}{I_1} \right|_{I_2=0} \\
 z_{11} &= R_4 + R_2 \parallel (R_1 + R_3) \\
 &= R_4 + \frac{R_2(R_1 + R_3)}{R_1 + R_2 + R_3}
 \end{aligned}$$

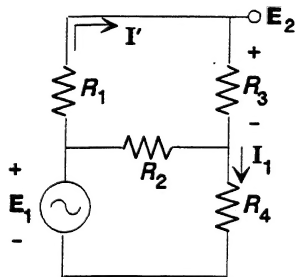


$$z_{12} = \left. \frac{E_1}{I_2} \right|_{I_1=0}$$



$$\begin{aligned}
 I' &= \frac{R_2(I_2)}{(R_1 + R_2) + R_3} \\
 E_1 &= I'R_2 + I_2R_4 \\
 &= \frac{R_2R_3I_2}{R_1 + R_2 + R_3} + R_4I_2
 \end{aligned}$$

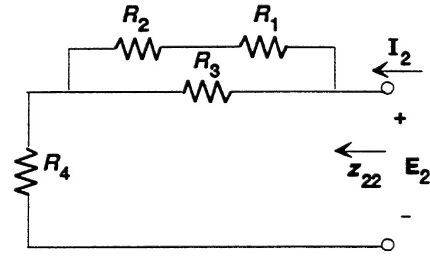
$$\text{and } z_{12} = \frac{E_1}{I_2} = \frac{R_2R_3}{R_1 + R_2 + R_3} + R_4 = \frac{R_2R_3 + R_4(R_1 + R_2 + R_3)}{R_1 + R_2 + R_3}$$



$$\begin{aligned}
 E_2 &= I'R_3 + I_1R_4 \\
 \text{CDR: } I' &= \frac{R_2(I_1)}{(R_1 + R_3) + R_2} \\
 E_2 &= \frac{R_2R_3I_1}{R_1 + R_2 + R_3} + I_1R_4
 \end{aligned}$$

$$\text{and } z_{21} = \frac{E_2}{I_1} = \frac{R_2R_3}{R_1 + R_2 + R_3} + R_4 = \frac{R_2R_3 + R_4(R_1 + R_2 + R_3)}{R_1 + R_2 + R_3}$$

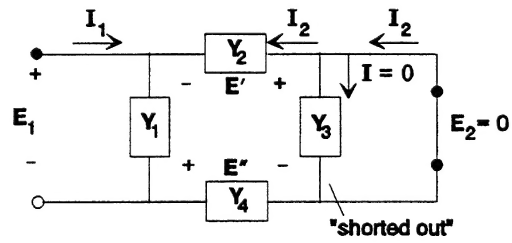
$$z_{22} = \left. \frac{E_2}{I_2} \right|_{I_1=0}$$



$$\begin{aligned} z_{22} &= R_4 + R_3 \parallel (R_1 + R_2) \\ &= R_4 + \frac{R_3(R_1 + R_2)}{R_3 + (R_1 + R_2)} \end{aligned}$$

20. a.  $y_{11} = \left. \frac{I_1}{E_1} \right|_{E_2=0}$

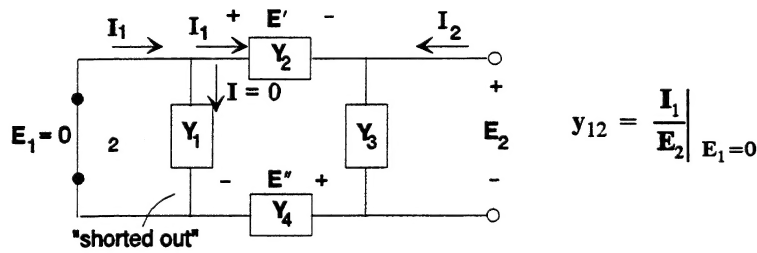
$$\begin{aligned} y_{11} &= Y_1 + Y_2 \parallel Y_4 \\ &= Y_1 + \frac{Y_2 Y_4}{Y_2 + Y_4} \\ &= \frac{Y_1(Y_2 + Y_4) + Y_2 Y_4}{Y_2 + Y_4} \end{aligned}$$



$$y_{21} = \left. \frac{I_2}{E_1} \right|_{E_2=0} \text{ (using the above diagram)}$$

$$E_1 = \frac{I_2}{Y_1} = -(E' + E'') = -\left[ \frac{I_2}{Y_2} + \frac{I_2}{Y_4} \right] = -I_2 \left[ \frac{1}{Y_2} + \frac{1}{Y_4} \right]$$

$$\text{and } E_1 = -I_2 \left[ \frac{Y_4 + Y_2}{Y_4 Y_2} \right] \text{ with } y_{21} = \frac{I_2}{E_1} = -\frac{Y_2 Y_4}{Y_2 + Y_4}$$



$$y_{12} = \left. \frac{I_1}{E_2} \right|_{E_1=0}$$

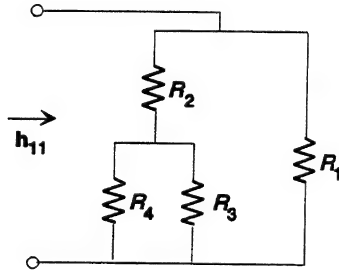
$$E_2 = \frac{I_1}{Y_3} = -(E' + E'') = -\left[ \frac{I_1}{Y_2} + \frac{I_1}{Y_4} \right] = -I_1 \left[ \frac{1}{Y_2} + \frac{1}{Y_4} \right]$$

$$\text{and } y_{12} = -\frac{Y_2 Y_4}{Y_2 + Y_4} = y_{21}$$

$$y_{22} = \left. \frac{I_2}{E_2} \right|_{E_1=0} \quad y_{22} = Y_3 + Y_2 \parallel Y_4 = Y_3 + \frac{Y_2 Y_4}{Y_2 + Y_4}$$

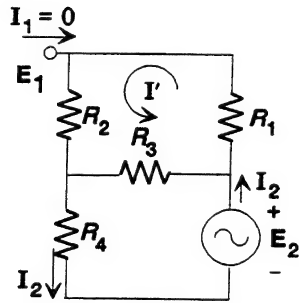
$$= \frac{Y_3(Y_2 + Y_4)Y_2 Y_4}{Y_2 + Y_4}$$

22. a.



$$h_{11} = \left. \frac{E_1}{I_1} \right|_{E_2=0}$$

$$= Z_i = R_1 \parallel (R_2 + R_3 \parallel R_4)$$



$$h_{12} = \left. \frac{E_1}{E_2} \right|_{I_1=0}$$

$$E_1 = I' R_2 + I_2 R_4$$

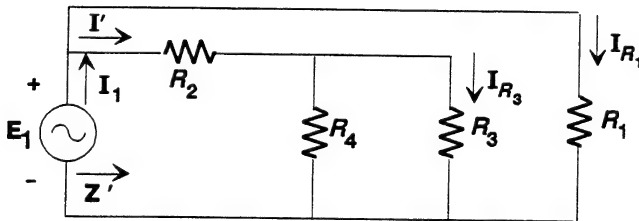
$$I' = \frac{R_3(I_2)}{R_1 + R_2 + R_3}$$

$$\therefore E_1 = \frac{R_2 R_3 I_2}{R_1 + R_2 + R_3} + I_2 R_4$$

$$\text{and } I_2 = \frac{E_2}{Z'} = \frac{E_2}{R_4 + R_3 \parallel (R_1 + R_2)}$$

$$E_1 = \left[ \frac{R_2 R_3}{R_1 + R_2 + R_3} + R_4 \right] \left[ \frac{E_2}{R_4 + \frac{R_3 R_1 + R_2 R_3}{R_1 + R_2 + R_3}} \right]$$

$$\text{and } h_{12} = \frac{E_1}{E_2} = \frac{R_2 R_3 + R_4(R_1 + R_2 + R_3)}{R_1 R_3 + R_2 R_3 + R_4(R_1 + R_2 + R_3)}$$



$$Z' = R_2 + R_3 \parallel R_4$$

$$I_{R_1} = \frac{(Z')(I_1)}{Z' + R_1}$$

$$I' = \frac{R_1 I_1}{R_1 + Z'}$$

$$I_{R_3} = \frac{R_4 I'}{R_4 + R_3} = \frac{R_4}{R_4 + R_3} \left[ \frac{R_1(I_1)}{R_1 + Z'} \right]$$

$$= \frac{R_1 R_4 I_1}{(R_3 + R_4)(R_1 + Z')}$$

$$I_2 = -I_{R_1} - I_{R_3} = \frac{-Z'I_1}{Z' + R_1} - \frac{R_1 R_4 I_1}{(R_3 + R_4)(R_1 + Z')}$$

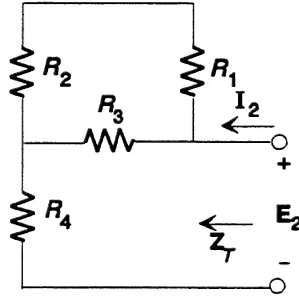
$$h_{12} = \left. \frac{I_2}{I_1} \right|_{E_2=0} = - \left[ \frac{Z'}{Z' + R_1} + \frac{R_1 R_4}{(R_3 + R_4)(R_1 + Z')} \right]$$

$$= - \frac{1}{R_1 + Z'} \left[ Z' + \frac{R_1 R_4}{R_3 + R_4} \right]$$

$$h_{22} = \left. \frac{I_2}{E_2} \right|_{I_1=0} = \frac{1}{Z_T}$$

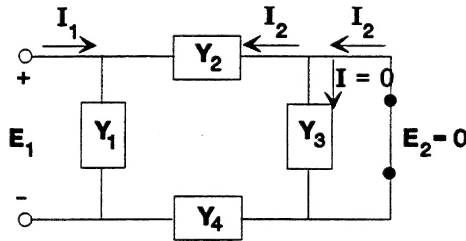
$$Z_T = R_4 + R_3 \parallel (R_1 + R_2)$$

$$h_{22} = \frac{1}{R_4 + R_3 \parallel (R_1 + R_2)}$$



A Y-Δ conversion would have simplified the problem to one similar to Fig. 26.70.

24.

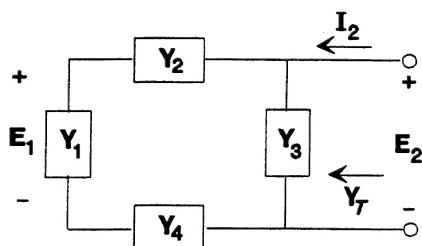


$$h_{11} = \left. \frac{E_1}{I_1} \right|_{E_2=0} = \frac{1}{Y_T} = \frac{1}{Y_1 + Y_2 \parallel Y_4}$$

$$h_{21} = \left. \frac{I_2}{I_1} \right|_{E_2=0} : \text{CDR} \rightarrow I_2 = \frac{-Z_1(I_1)}{Z_1 + Z_2 + Z_4} = \frac{-1/Y_1(I_1)}{1/Y_1 + 1/Y_2 + 1/Y_4}$$

$$= \frac{-1/Y_1(I_1)}{\frac{Y_2 Y_4 + Y_1 Y_4 + Y_1 Y_2}{Y_1 Y_2 Y_4}}$$

$$\text{and } h_{21} = - \frac{Y_2 Y_4}{Y_2 Y_4 + Y_1 Y_4 + Y_1 Y_2}$$



$$h_{12} = \left. \frac{E_1}{E_2} \right|_{I_1=0}$$

$$\begin{aligned} \text{VDR: } E_1 &= \frac{Z_1(E_2)}{Z_1 + Z_2 + Z_4} \\ &= \frac{1/Y_1 (E_2)}{1/Y_1 + 1/Y_2 + 1/Y_4} \end{aligned}$$

$$\text{and } h_{12} = \frac{Y_2 Y_4}{Y_2 Y_4 + Y_1 Y_4 + Y_1 Y_2}$$

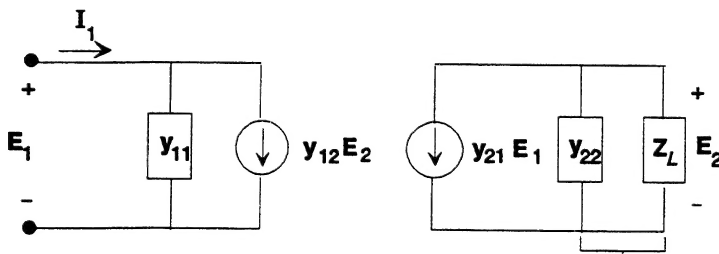
$$h_{22} = \left. \frac{I_2}{E_2} \right|_{I_1=0} = Y_T \text{ (using the above figure)}$$

$$\begin{aligned} Y_T &= Y_3 + Y_1 \parallel Y_2 \parallel Y_4 \\ &= Y_3 + \frac{Y_1 Y_2 Y_4}{Y_1 Y_2 + Y_1 Y_4 + Y_2 Y_4} \end{aligned}$$

$$\begin{aligned} 26. \quad a. \quad Z_i &= \frac{E_1}{I_1} = h_i - \frac{h_r h_f Z_L}{1 + h_o Z_L} \\ &= 1 \text{ k}\Omega - \frac{(4 \times 10^{-4})(50)(2 \text{ k}\Omega)}{1 + \left[ \frac{1}{40 \text{ k}\Omega} \right] (2 \text{ k}\Omega)} = 961.9 \Omega \end{aligned}$$

$$b. \quad Z_o = \frac{1}{h_o - \frac{h_r h_f}{h_i + R_s}} = \frac{1}{\frac{1}{40 \text{ k}\Omega} - \frac{(4 \times 10^{-4})(50)}{1 \text{ k}\Omega + 0}} = 200 \text{ k}\Omega$$

28.



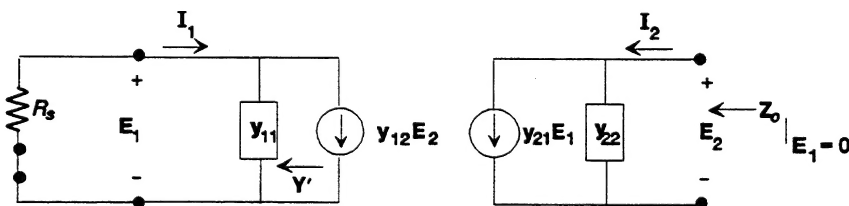
$$\begin{aligned} 1/y_{22} \parallel Z_L &= \frac{1/y_{22} Z_L}{1/y_{22} + Z_L} \\ &= \frac{Z_L}{1 + y_{22} Z_L} \end{aligned}$$

$$E_2 = -y_{21} E_1 \left[ \frac{Z_L}{1 + y_{22} Z_L} \right]$$

$$I_1 = E_1 y_{11} + y_{12} E_2 = E_1 y_{11} + y_{12} \left[ -y_{21} E_1 \left[ \frac{Z_L}{1 + y_{22} Z_L} \right] \right]$$

$$\frac{I_1}{E_1} = y_{11} - \frac{y_{12}y_{21}Z_L}{1 + y_{22}Z_L}$$

and  $Z_i = \frac{E_1}{I_1} = \frac{1}{y_{11} - \frac{y_{12}y_{21}Z_L}{1 + y_{22}Z_L}}$



$$Y' = y_{11} + \frac{1}{R_s}$$

$$E_1 = \frac{-y_{12}E_2}{Y'} = \frac{-y_{12}E_2}{y_{11} + \frac{1}{R_s}} = \frac{-y_{12}R_s E_2}{y_{11}R_s + 1}$$

$$I_2 = y_{21}E_1 + y_{22}E_2 = y_{21} \left[ \frac{-y_{12}R_s E_2}{y_{11}R_s + 1} \right] + y_{22}E_2$$

$$\frac{I_2}{E_2} = -\frac{y_{12}y_{21}R_s}{y_{11}R_s + 1} + y_{22}$$

$$\text{and } Z_o = \left. \frac{E_2}{I_2} \right|_{E_1=0} = \frac{1}{y_{22} - \frac{y_{12}y_{21}R_s}{1 + y_{11}R_s}}$$

30. a.  $\Delta_h = h_{11}h_{22} - h_{12}h_{21} = (10^3)(20 \times 10^{-6}) - (2 \times 10^{-4})(100)$   
 $= 20 \times 10^{-3} - 20 \times 10^{-3} = 0$

$$z_{11} = \frac{\Delta_h}{Z_{22}} = 0 \Omega, z_{12} = \frac{h_{12}}{h_{22}} = \frac{2 \times 10^{-4}}{20 \times 10^{-6} \text{ S}} = 10 \Omega$$

$$z_{21} = \frac{-h_{21}}{h_{22}} = \frac{-100}{20 \times 10^{-6} \text{ S}} = -5 \text{ M}\Omega, z_{22} = \frac{1}{h_{22}} = 50 \text{ k}\Omega$$

b.  $y_{11} = \frac{1}{h_{11}} = \frac{1}{10^3 \Omega} = 10^{-3} \text{ S}, y_{12} = \frac{-h_{12}}{h_{11}} = \frac{-2 \times 10^{-4}}{10^3 \Omega} = -2 \times 10^{-7} \text{ S}$

$$y_{21} = \frac{h_{21}}{h_{11}} = \frac{100}{10^3 \Omega} = 100 \times 10^{-3} \text{ S}, y_{22} = \frac{\Delta_h}{h_{11}} = 0 \text{ S}$$

